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REPORT

A transportable satellite earth station

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Summary

The report describes the main factors that were taken into account in establishing the design of a transportable transmitting earth station for relaying television signals via a satellite. The realisation of a practical system to work with the Orbital Test Satellite (OTS) and the European Communications Satellite (ECS) is outlined together with details of the link power budget and results of the performance achieved. A brief review of operational experience by the Television Service up to the time of writing is also included.

Issued under the Authority of

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A TRANSPORTABLE SATELLITE EARTH STATION

M.W. Harman, C.Eng., M.I.E.R.E., C. Gandy, B.Sc.

1. Introduction

The continuing availability of the Orbital Test Satellite (OTS), and a proposal for the European Broadcasting Union to lease two transponders in the European Communications Satellite (ECS) system, proved an attractive basis to equip the Television Service with a transportable satellite earth station or terminal. The completed unit was made ready for service during the summer of 1981 and was handed over to BBC Television Outside Broadcasts Communications Group in October 1981.

Initial studies were carried out to assess various forms of vehicle construction as well as the design features that would enable the equipment to be compatible with existing BBC outside broadcast units using terrestrial radio links. Also the equipment had to fit in with the custom and practice of outside-broadcast programme production as an operational unit. Construction commenced in 1980 and took eighteen months to complete.

In November 1981, three live programmes for BBC 1 were successfully transmitted from Guernsey, in the Channel Islands, a site from which terrestrial circuits are impracticable. On this occasion, various aspects of the use of the terminal in a satellite link were demonstrated for the first time. A photograph of the terminal in operation is shown in Fig. 1.

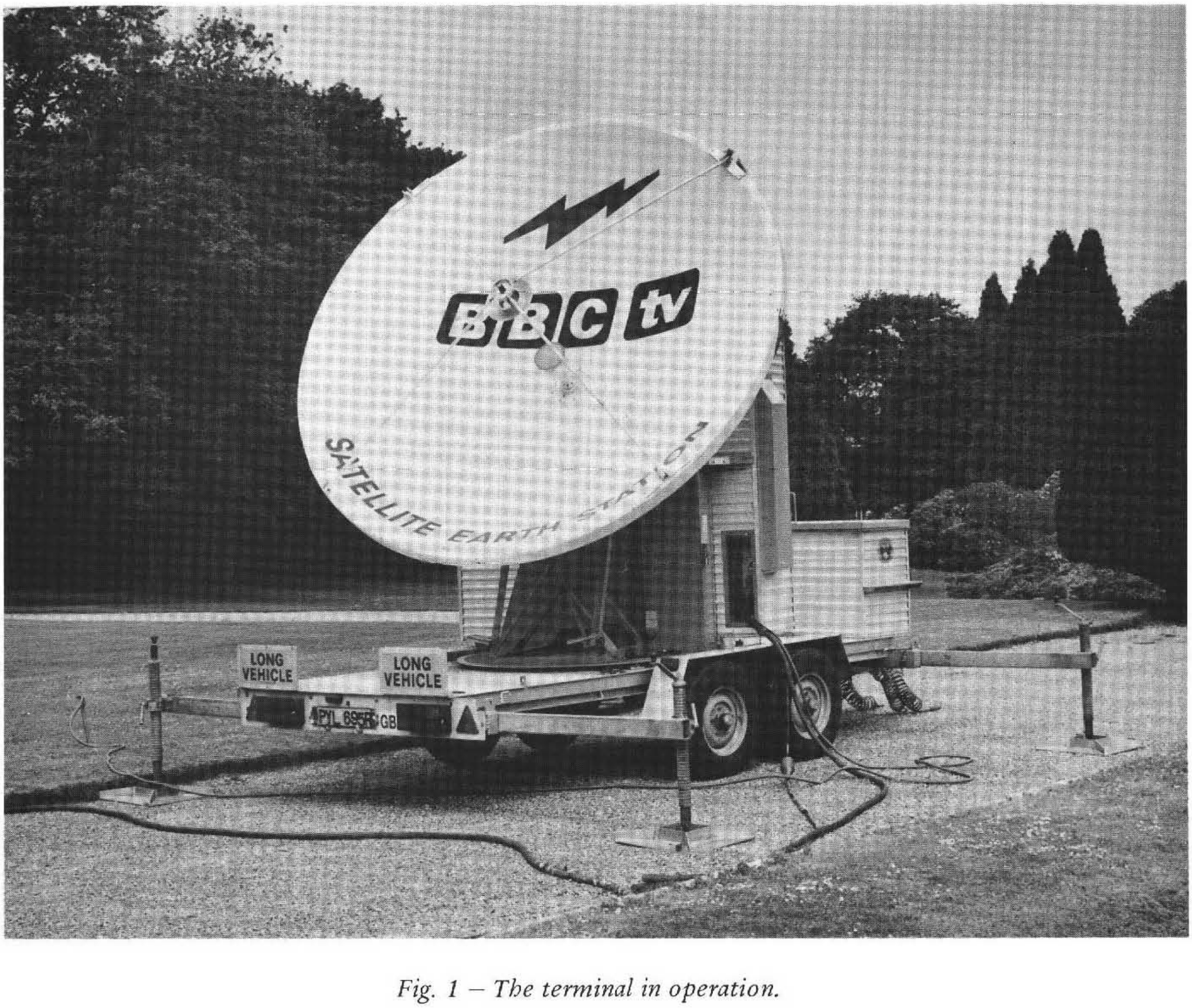

Fig. 1 – The terminal in operation.

2. Factors affecting transportable terminal design and operation

2.1. General

In addition to booking the satellite, a transmitting and a receiving earth station need to be established before a television circuit can be made available within the satellite footprint. These must be designed to operate using available satellite systems. At the time the project was undertaken the only European satellite suitable for use with a small transportable earth station was the OTS, which was intended to prove transponder designs and techniques planned for subsequent use on the ECS. The OTS incorporated more flexibility than would be built into its successor, which made it easier to operate in conjunction with small transportable earth stations. It is hoped that later flight numbers in the ECS programme will cater more for the needs of transportable up-links.

2.2. Frequency co-ordination

The frequencies allocated to up-links in the European fixed satellite service cover the band 14.0 – 14.5 GHz. This gave rise to some concern because the transponders most likely to be used on both the OTS and the ECS all have up-link frequencies in the 14.25 – 14.5 GHz part of the band which is also shared with terrestrial fixed services.

The siting of a transportable up-link at a location which gives access to the satellite means that without prior co-ordination, through the Department of Trade and Industry (DTI) and, where relevant, overseas PTT organisations, there would be a risk of causing severe and unexpected interference to fixed service users. When this project was planned the number of fixed services registering to share this part of the frequency spectrum in the United Kingdom was small and there was no immediate problem apart from obtaining national frequency approval to permit operations in the national co-ordination area of the UK mainland, and periodically submitting a list of sites and duration of transmissions to the DTI.

Unfortunately, the procedure for international co-ordination remains a problem when using the shared part of the band because a period of three to six months is required for the clearance of transportables. Also the sites have no long term status, unlike permanent large earth stations for which the procedure was formulated.

Alternatively, if changes in the ECS allocation arrangements could be negotiated, it would be possible to use transponders in the exclusive satellite up-link part of the band from 14.0 – 14.25 GHz.

2.3. Satellite down-link characteristics

As far as operational use of the transportable terminal is concerned, it is assumed that reception would take place via an established fixed earth station such as the Goonhilly station of British Telecom. However, the question arises of equipping the transportable terminal to receive the satellite transmission for monitoring and various experimental purposes.

Differences in the down-link effective isotropic radiated power (e.i.r.p.) of transponders can influence the design of a transportable terminal. Experience has shown that the ability to monitor the up-link transmission quality, after translation in the satellite, is an invaluable asset. To date, this has been achieved by booking the OTS channel 4 transponder which has a spotbeam down-link illustrated in Fig. 2, with a maximum e.i.r.p. of 47.1 dBW. In the UK, this reduces to 45.6 dBW in the London area, and to 44.1 dBW at the western extremities of Great Britain.

A practical antenna arrangement suitable for a transportable terminal in conjunction with a relatively simple receiving chain could have a gain-to-noise temperature ratio (G/T) of about 22 dBK^{-1}. It is therefore possible to receive with a carrier-to-noise ratio (C/N) of about 13 dB in clear air when working with the OTS spot beam near the western extremities of Great Britain, using a 40 MHz bandwidth. This can provide a high-quality picture.

Monitoring the transmission leaving the satellite is more difficult when receiving a Eurobeam down-link. Effective, but low quality, monitoring is possible using a restricted receiver bandwidth to increase the C/N when working below the usual threshold of about 10 dB C/N in 40 MHz. The OTS channel 2 down-link (Eurobeam A) has a maximum e.i.r.p. of about 39.0 dBW, reducing to 38.3 dBW in the London area and 38.0 dBW along the west coast.

Considering the ECS programme, two of the four transponders suitable for television use have been leased by the EBU from Interim EUTELSAT. The intention is for circuits to be made available to EBU members for exchange of programmes within the Eurovision network

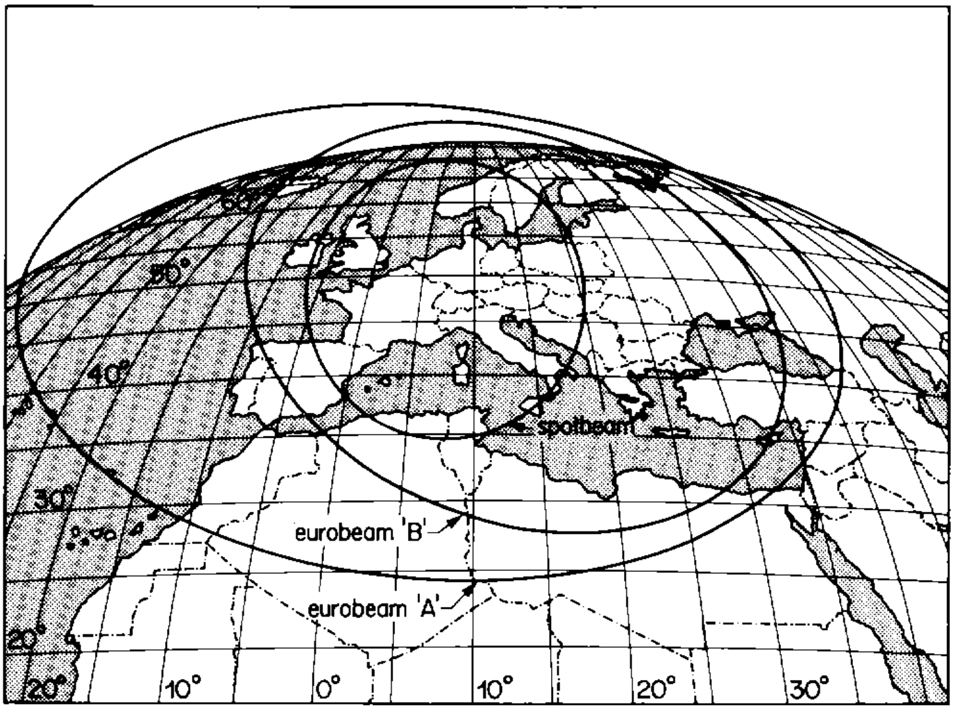

Fig. 2 – OTS down-link beams.

using large PTT earth stations. This means that satellite transmissions will take place via the ECS Eurobeam down-link which has a pre-launch e.i.r.p. specification of 38.3 dBW at beam centre and, subject to final pointing, about 37.3 dBW towards southern England. There may however, be more specific needs of certain EBU members in the use of transportable terminals. For example ECS transponders making use of spotbeam 'west' down-links, and up-links in the 14.0 – 14.25 GHz band could be made available for occasional use under terms yet to be agreed, perhaps using the spare satellite. This would assist in solving the double problem of up-link frequency co-ordination with fixed terrestrial circuits and providing adequate flux density for reception check purposes on board the transportable terminal. The spotbeam would also permit satisfactory reception by fixed stations of lower cost than those required for Eurobeam reception.

3. Transportable earth station up-link requirements

One aspect of the satellite link system that must be considered is the satellite transponder performance, both in terms of the required incident power flux density (i.p.f.d.) and the figure of merit (G/T). The up-link e.i.r.p. required to saturate the transponder in clear weather depends on the i.p.f.d. and the propagation spreading loss*, which in turn depends on the satellite orbital position and the location of the up-link terminal. In the UK, working to satellites stationed at 10° East, the spreading loss is 162.8 dB.

When radiating from small earth stations it is essential to have the transponder switched to maximum gain, in which case the OTS requires an i.p.f.d. of around $-85\,\mathrm{dBWm}^{-2}$ to saturate the transponder[1], depending on the transponder in use. It follows therefore, that the up-link e.i.r.p. should be 77.8 dBW; for most of the UK an up-link e.i.r.p. of about 77 dBW would be sufficient, operating the satellite high power amplifier (h.p.a.) at 1 dB below the input power for saturation. Assuming an average G/T for the 120 MHz bandwidth transponders on the OTS of about 0 dB, the up-link carrier-to-noise ratio at the satellite is then approximately 21 dB, assuming an effective 40 MHz bandwidth.

Although an increase in the e.i.r.p. from the transportable terminal, coupled with a reduction of the transponder gain would improve the up-link C/N, no increase in output from the satellite is possible in order to make a corresponding down-link improvement. There are therefore diminishing returns as the up-link e.i.r.p. is increased.

An antenna diameter of 3 m emerged as the optimum size for a circular dish consistent with trailer portability and headroom restrictions due to low bridges, etc. Reflector antennas of 3 m diameter are available with a gain of 51 dBi at 14.25 GHz; for the desired e.i.r.p. the r.f. power at the feed horn would need to be 26 dBW. As a basis on which the whole design concept for the transportable terminal could evolve, a commercially available compact and light-weight h.p.a employing a 600 watt (27.8 dBW) travelling-wave tube (t.w.t.) was explored. Provided that the system losses could be kept to 1.8 dB, the e.i.r.p. requirement could be met.

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* Using decibel units, the e.i.r.p. minus the spreading loss, gives the i.p.f.d. for free-space propagation; clear weather atmospheric attenuation is about 0.5 dB for the UK.

A travelling-wave tube was considered preferable to a klystron because of its wideband nature, the entire up-link band from 14.0 – 14.5 GHz being covered without retuning being necessary.

As a precaution against loss of programme due to failure of the h.p.a., it was planned to use a dual redundant h.p.a. configuration, with the possibility of a simple modification which would allow the amplifier outputs to be combined to give up to 3 dB more power. This could prove necessary when using the ECS because the i.p.f.d. for saturation is expected to be higher than for the OTS. Any final decision on combining must await the actual in-flight performance figures for the ECS. An increase in h.p.a. output may, however, lead to co-ordination problems with fixed satellite services; it is expected that with the present antenna, the maximum transmitter power would have to be kept below 600 watts in order to protect Intelsat circuit from interference.

The alternative approach of increasing the size of the antenna was rejected because, for the available circular antennas, it would imply some form of folding or prefabricated reflector being assembled on site. This would not meet the operational needs of speed and reliability and could result in damage to the reflector causing degradation of the radiation pattern.

4. Realisation of a practical transportable satellite terminal

4.1. Basic principles

In consultation with BBC Television Outside Broadcasts, it was decided to build the terminal onto a trailer which could be towed to the required location by a standard radio-link vehicle, rather than building it into a purpose-built vehicle which would be very costly. Another advantage of adopting this approach is that in the event of the towing vehicle breaking down another could be sent to replace it, which would not be possible in the case of a special vehicle. An important requirement was to mount all the heavy and bulky r.f. units together with the antenna on the trailer, but allowing certain functions and a duplicate set of controls to be housed in portable equipment which could be transferred to and operated from the radio-link vehicle. Another important requirement was that the terminal should be powered from a single-phase mains supply. The layout of the trailer units was designed to provide maximum r.f. efficiency by mounting the equipment bays and antenna close together and using the shortest possible transmission lines. A general view of the complete trailer, coupled to a radio-link van ready for towing, is shown in Fig. 3.

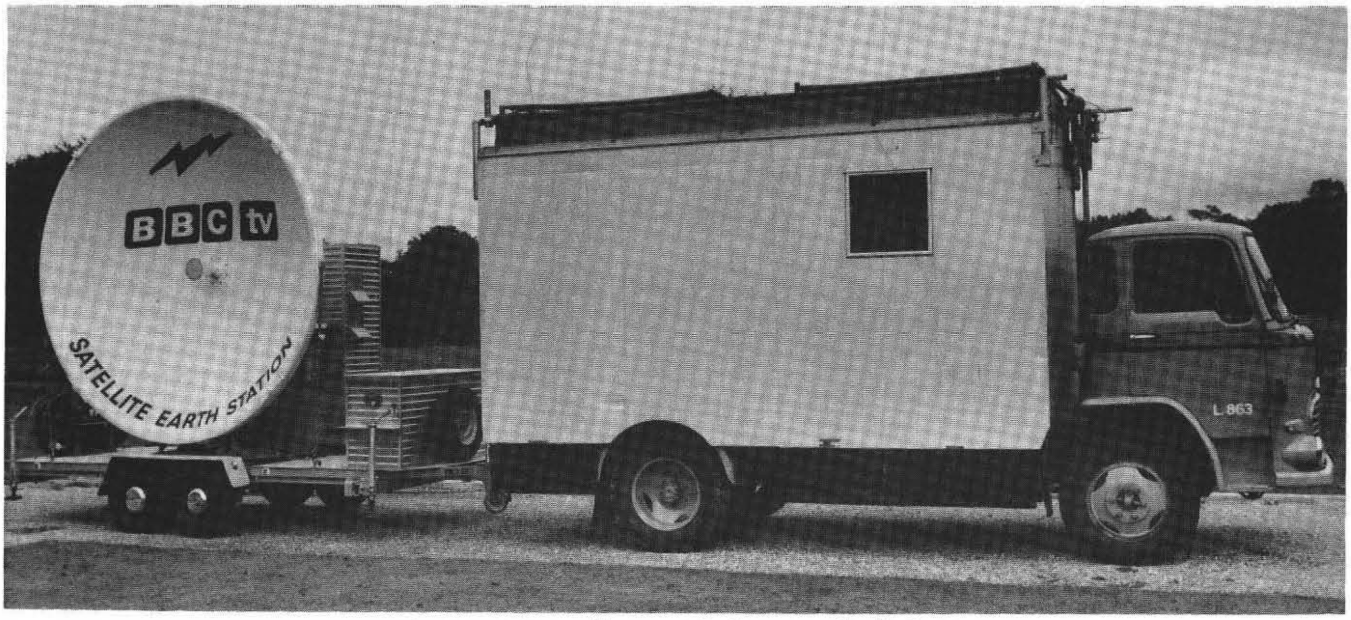

Fig. 3 – The trailer coupled to a radio-link van.

4.2. The trailer configuration

Fig. 4 shows in more detail the mechanical design of the trailer which incorporates a rotatable horizontal platform covering 360° of azimuth, on which the antenna and equipment bays are mounted. The maximum elevation angle is limited to 45° which allows access to both the OTS and ECS in most parts of Europe.

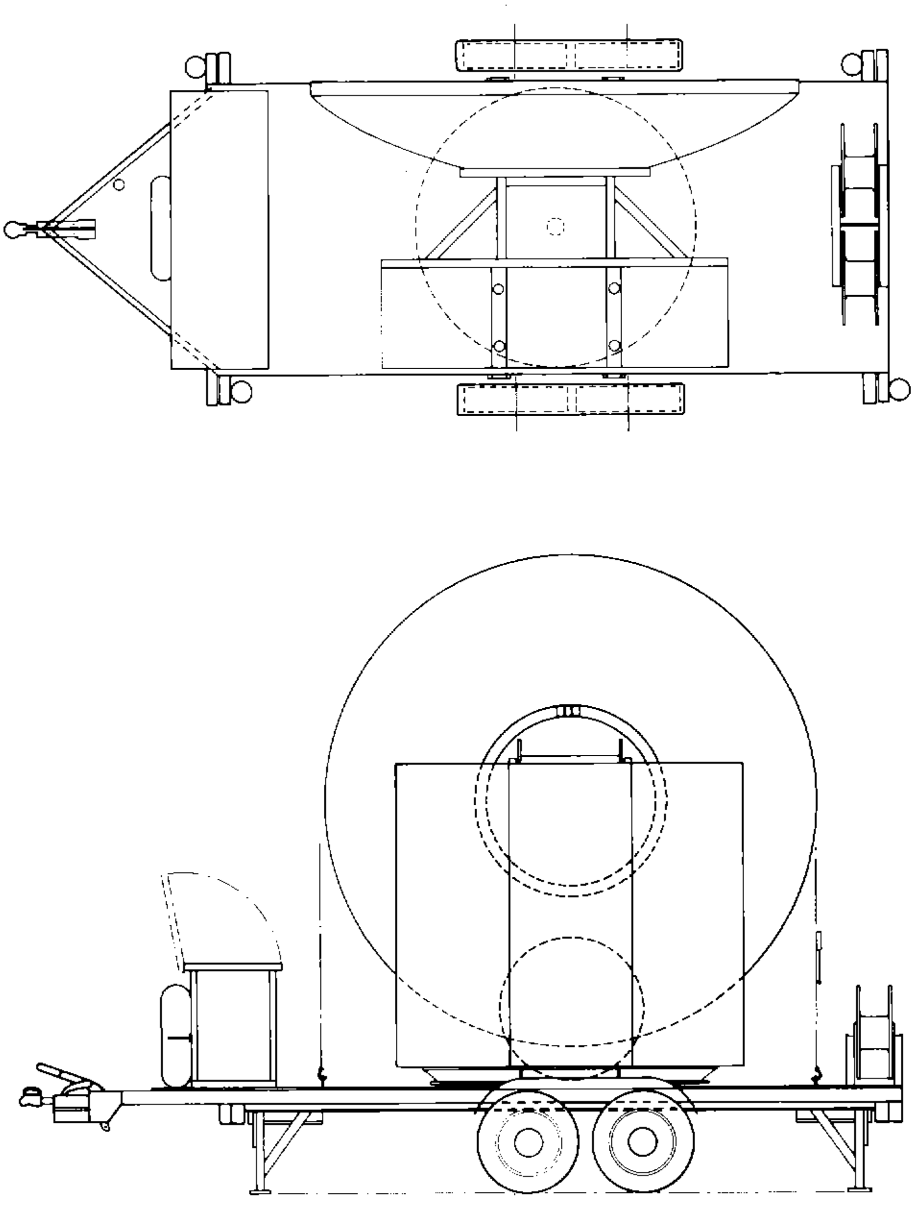

Fig. 4 – Plan and side elevation of the trailer.

4.3. The equipment chain

Fig. 5 is a block diagram of the trailer-borne signal equipment. The drive for the h.p.a. is derived from a frequency-agile up-converter which accepts the modulated carrier and supplies an output on any one of six selectable channels after two stages of frequency conversion. The chain also includes pre-emphasis and energy dispersal modules. An optional sound subcarrier may also to be fed to the modulator.

A receiving chain is provided to check the satellite output-signals; this includes a GaAs FET low noise amplifier (l.n.a.), a frequency-agile down-converter, an a.g.c. amplifier and an f.m.

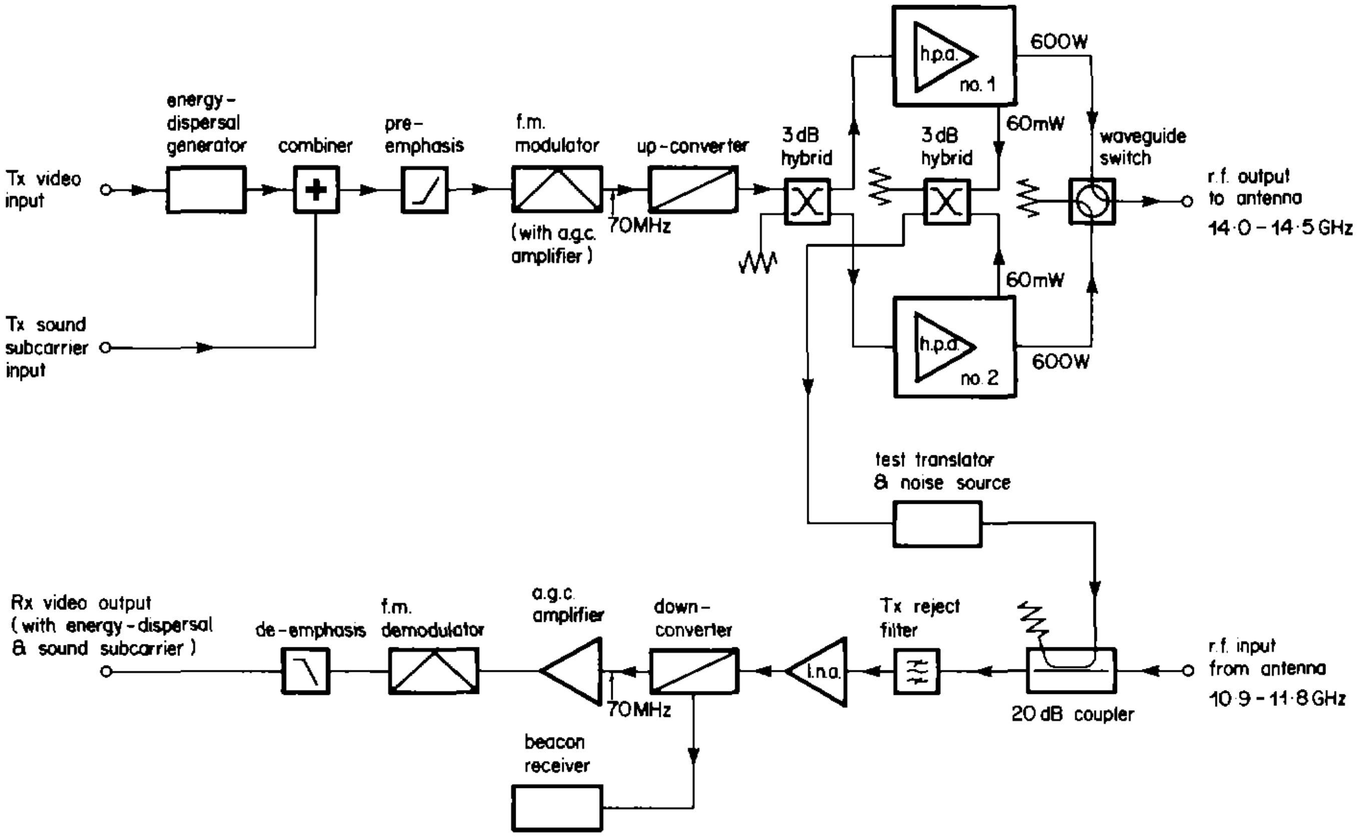

Fig. 5 — Block diagram of the signal equipment on the trailer.

demodulator. The l.n.a. input is filtered to remove any residual 14 GHz transmitted signals so that the receiver can be used during transmission. The receiver chain also allows monitoring of both the OTS and ECS beacons. When a spotbeam downlink is in use it is possible to check locally for distortion in the satellite output signal.

To add to the flexibility of operating the terminal on site, the baseband video and audio subcarrier interface units, and a set of repeated controls are contained in three ruggedised portable cases as shown in Fig. 6. These include antenna positioning controls, h.p.a. status indicators, a channel selector and meters for the check-receiver a.g.c. and a beacon signal level. These units would normally be operated remotely from inside the radio-link van and were specifically designed to for the available space inside such a vehicle. They are connected to the trailer by means of up to 120 m of multiway television camera cable.

4.4. The high-power amplifier

Until recently, it would have been necessary to employ an h.p.a. using a klystron having an r.f. power of up to 2 kW and requiring a three-phase mains supply; typically the weight would have been about 700 kg. However, a newly developed 600 W t.w.t. had recently become available which was compatible with the various voltages and currents produced by an existing proprietary power supply which operates from a single-phase mains supply. The power supply manufacturer was able to develop a suitable h.p.a. using the new t.w.t. Both the r.f. unit and the power supply are capable of being housed in standard equipment bays and have a total weight of only 114 kg; this enabled all the r.f. units, including the h.p.a, to be housed in an equipment cabinet immediately behind the antenna.

The complete assembly was fixed to the rotating turntable so that the waveguide connection to the antenna could be left permanently connected and pressurised. The much reduced size of the h.p.a. made it possible to employ two units in a dual redundant configuration allowing automatic switchover to the standby h.p.a. in the event of failure, this action taking about 100 ms.

Access to the equipment cabinet is normally only required during initial setting-up operations; the units it contains are accommodated in two bays one each side of a doorway and facing each other. They are depicted in Fig. 7 and Fig. 8, the contents being annotated

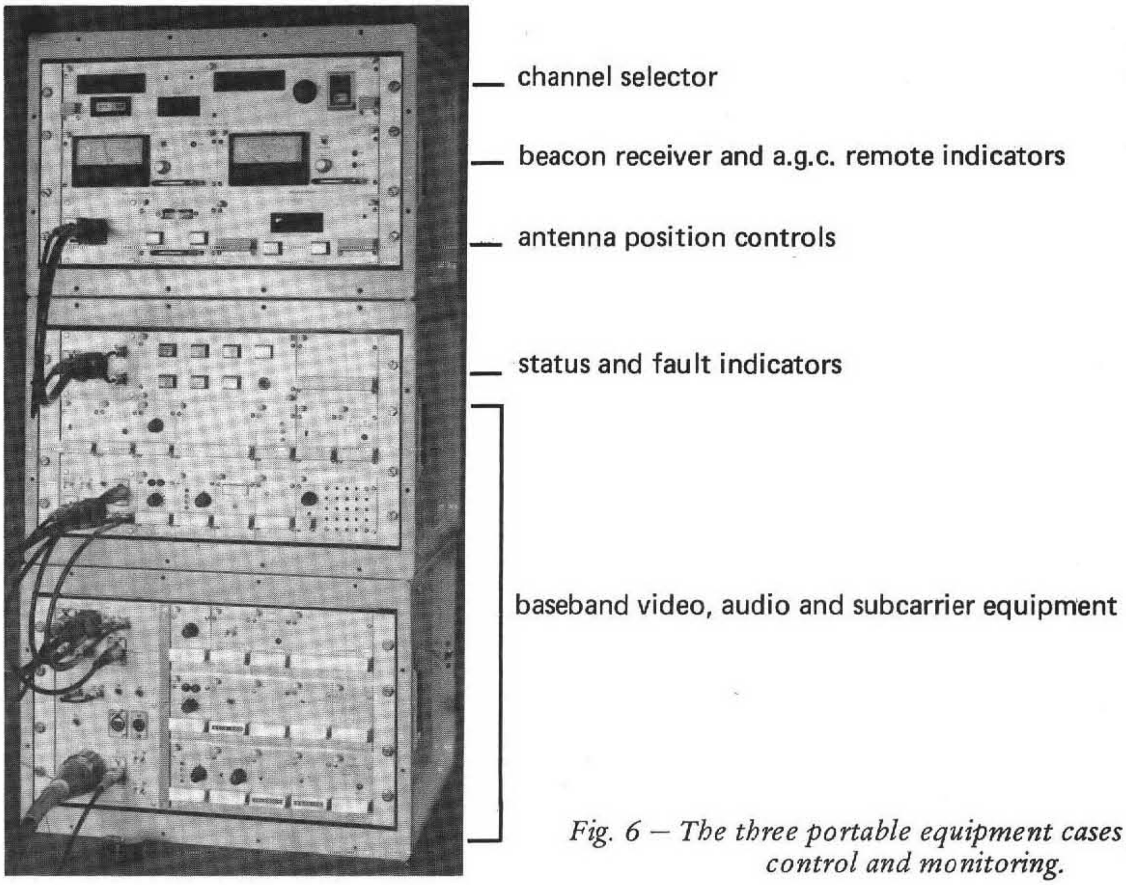
channel selector
beacon receiver and a.g.c. remote indicators
antenna position controls
status and fault indicators
baseband video, audio and subcarrier equipment

Fig. 6 – The three portable equipment cases for remote control and monitoring.

alongside each photograph. The total weight of the complete trailer is about 2.5 tonnes and the power consumption from a single-phase mains supply does not exceed 5 kVA.

4.5. Testing

In order to loop test the complete terminal equipment at s.h.f. a sample of the h.p.a. output is fed to a test translator which changes the frequency to correspond with the chosen satellite transponder. After attenuation, the signal is fed to the receiver input through a directional coupler between the antenna feed and the 'TX reject' filter. A calibrated noise source may also be connected at this point, and provided that the antenna is pointed at a region of the sky of low noise-temperature, the receiver gain and noise performance may be checked. The noise-temperature of the l.n.a. is better than 440 K in any channel over a total bandwidth of 850 MHz. Loop tests can also be undertaken at 70 MHz with the modem, and at baseband by crossplugging at the patch-panels on the right-hand cabinet bay.

A power budget is given in Appendix 9.1 for the terminal operating through the OTS channel 4 (spotbeam) transponder to a receiving earth station at Goonhilly, in Cornwall, which uses an 8 metre antenna. The measured performance figures using the built-in check-receiver with the OTS channel 4 transponder are given in Appendix 9.2.

4.6. Setting up for normal operation

The trailer is normally decoupled from the towing vehicle on site, being set up in a convenient position and orientation. The stabilising arms are extended and the trailer levelled by means of screw jacks. This is followed by fitting the sub-reflector to the antenna which is then aligned with reference to information provided on a map. Such maps have been supplied to the terminal operators, and indicate the required angles of elevation, azimuth and polarisation for both the OTS and ECS. The whole of Europe is covered in sections, an example being Fig. 9, which is a map for operation with the OTS in the UK. The maps are generated at Research Department using a series of computer programs.

The polarisation is adjusted manually by rotating the feed horn and the attached waveguide assembly. The turntable is then rotated manually to within ±7° of the wanted azimuth; this accuracy can usually be obtained with the aid of a hand-held magnetic compass. When so aligned, an electrically-driven, linear actuator is clamped to the turntable with a hydraulic calliper, as a means

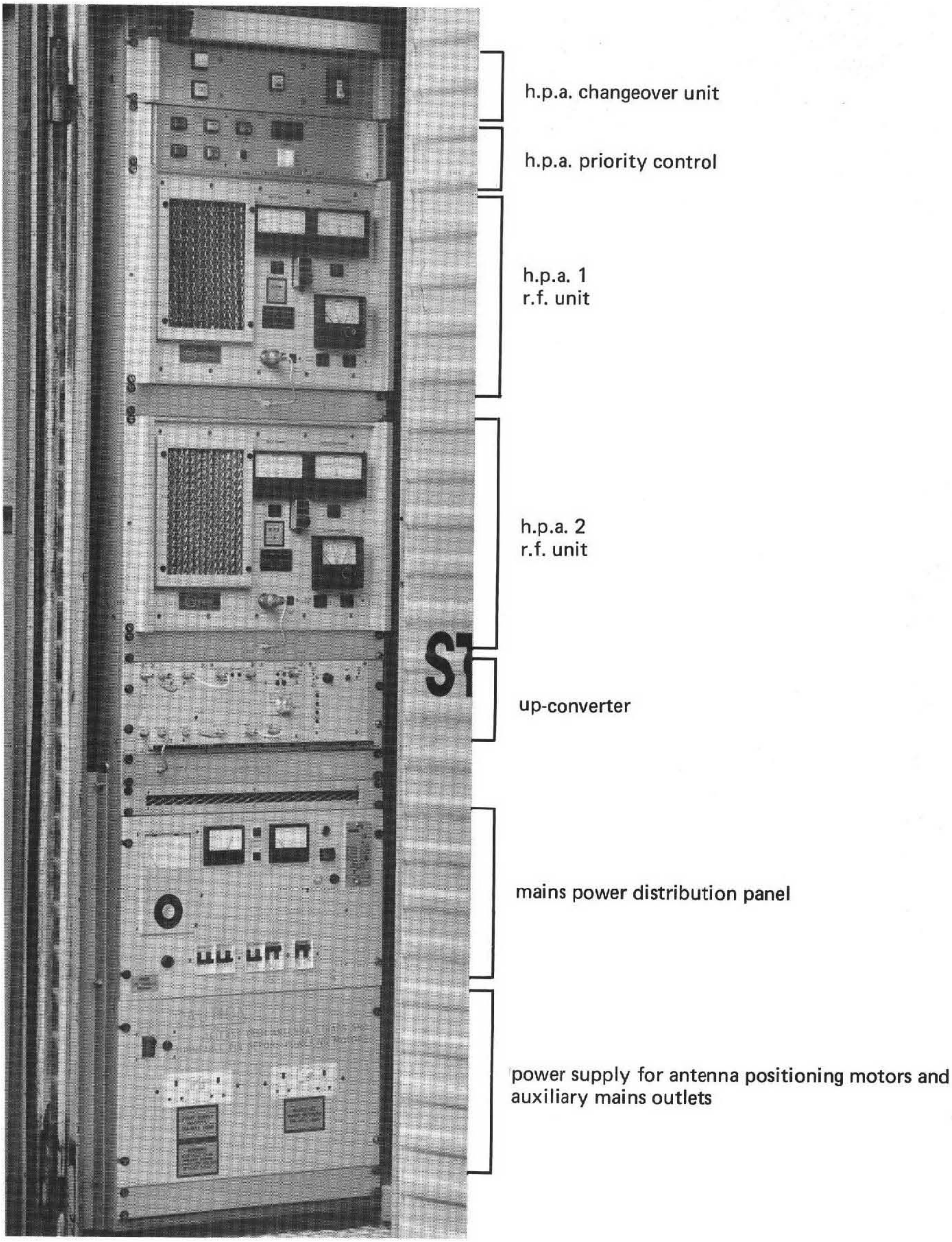
h.p.a. changeover unit
h.p.a. priority control
h.p.a. 1 r.f. unit
h.p.a. 2 r.f. unit
up-converter
mains power distribution panel
power supply for antenna positioning motors and auxiliary mains outlets

Fig. 7 – Left hand side equipment bay.

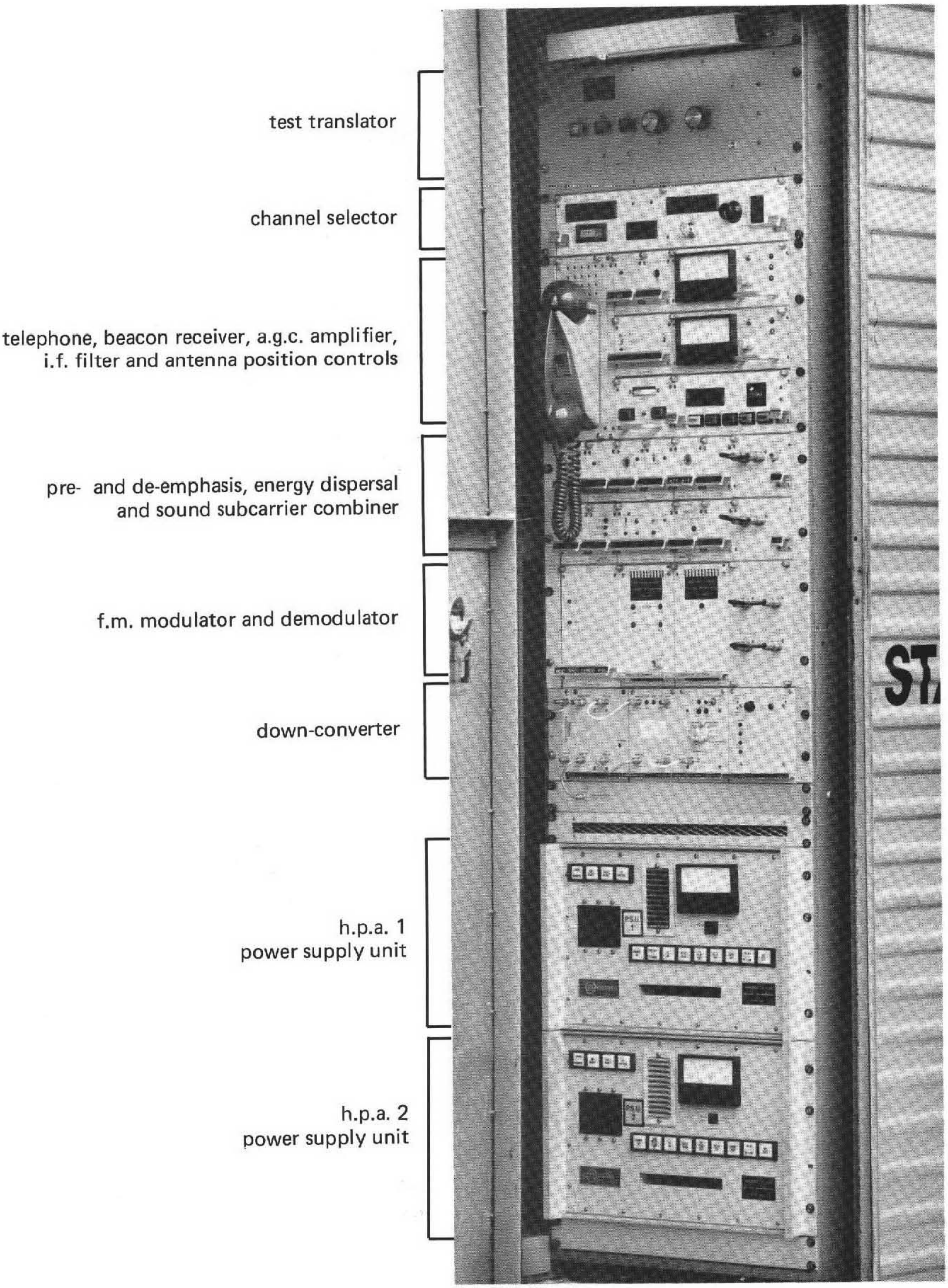
test translator
channel selector
telephone, beacon receiver, a.g.c. amplifier, i.f. filter and antenna position controls
pre- and de-emphasis, energy dispersal and sound subcarrier combiner
f.m. modulator and demodulator
down-converter
h.p.a. 1 power supply unit
h.p.a. 2 power supply unit
PSU 1
PSU 2

Fig. 8 – Right hand side equipment bay.

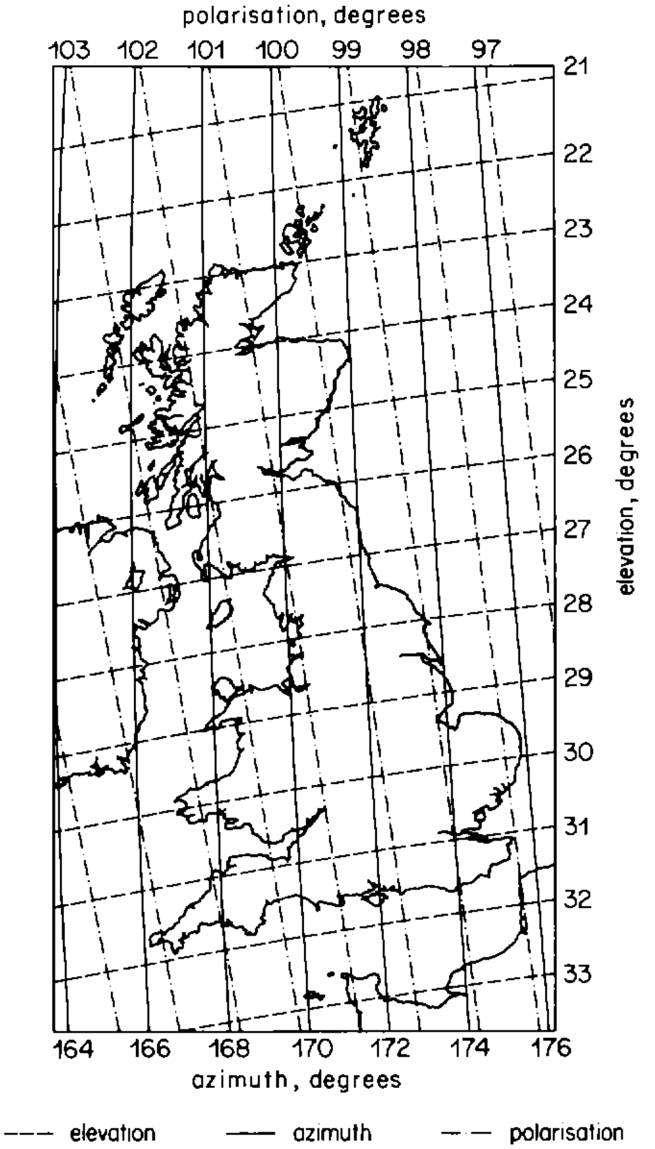

Fig. 9 – Antenna pointing map for a satellite at 10° E from the UK.

of fine azimuth adjustment. The power cables are then connected and the equipment switched on. The antenna is next driven electrically to the required elevation which is monitored by an electrical inclinometer attached to the rear of the reflector. When the required angle is reached the drive motors stop automatically, the setting is then within ± 0.5°. After selecting the appropriate channel it is necessary to search using the fine azimuth adjustment until a signal is detected by the beacon receiver, which is capable of working at 20 dB below the maximum level received from the OTS beacon. Precise pointing of the antenna is then achieved by maximising the reading on the beacon receiver signal-strength meter, using fine azimuth and elevation adjustments. The process of setting up the equipment as decribed takes about one hour. The photograph of Fig. 1 shows the trailer set up ready for use.

5. Voice communications

It is desirable that some form of two-way voice communication link other than the public telephone service, which is not always accessible on site, be established between the terminal, the receiving earth station and the BBC Switching Centre in London.

The optimum solution would appear to be the use of single-channel-per-carrier (s.c.p.c.) telephony channels sharing the satellite transponder. This would allow communication with not only the receiving earth station and the Switching Centre, but also other users of the transponder. However, the use of the saturated h.p.a. on board the terminal to carry the s.c.p.c. signal in addition to the main television signal requires further investigation.

A one-way information channel from the Switching Centre to the terminal has been provided using Insertion Communication Equipment (ICE)^2; this enables data, in digitally encoded form, to be transmitted during one or more lines of the field blanking period of the television waveform. Data, representing a summary of the signal parameters received at the Switching Centre, are transmitted within the normal terrestrial television broadcast signal and received at the transportable terminal where decoding takes place and the information is printed out. Such a channel is only possible when sufficient field strength is available from the local television transmitter. In principle a return path could be provided using ICE equipment at the OB site.

6. Transportable satellite earth station in operation

The completed transportable satellite earth station underwent rigorous acceptance tests prior to being handed over to Television Outside Broadcasts Communications Group. The terminal was first demonstrated at the Institution of Electrical Engineers in London, in October 1981. The trailer and radio-link van were located outside the premises from where both vision and sound signals were transmittted via the OTS, received at Goonhilly and then fed back over a terrestrial circuit to the auditorium as part of a presentation about satellite developments in broadcasting.

The first full-scale programme commitments were three live transmissions from Guernsey in November 1981. This location was well suited to the use of a satellite link because no permanent vision circuits exist from the island. To have arranged a terrestrial route to the Normandy coast and into the Eurovision circuit to London would have proved expensive and was administratively impractical. Vision circuit tests through Goonhilly were conducted satisfactorily using both the OTS channel 4 spotbeam transponder and the channel 2 Eurobeam transponder and this provided a contingency plan should any problems have arisen with satellite bookings.

During the final transmission from Guernsey weather conditions became severe. However, despite the terminal being in a very exposed position, the transmission was satisfactorily completed. This proved the stability of the antenna pointing and weather resistance of the equipment cabinet. A vision circuit with sound-in-syncs was established to the mainland for programmes, demonstrations and tests amounting to a total of about nine hours satellite time.

In February 1982 the terminal was used to link from an outside broadcast of an ice climb on Ben Nevis in Scotland. It was anticipated that the terminal would be operating at extremely low temperatures during this event and so, prior to the occasion, the terminal was subjected to a 24-hour exposure test with the air temperature at -20°C in an environmental test chamber at the premises of British Aerospace p.l.c., Stevenage; it emerged in full working order. The technical arrangements for the satellite link into Goonhilly worked well, but the climb was ultimately abandoned owing to bad weather.

This initial series of programmes demonstrated the practibility and reliability of the design. A more recent application for the terminal was during the 1982 World Cup football championships in Spain, from where, over a six-week period, satellite links were established for an aggregate of seventy-four hours.

A total of a hundred and twenty-two hours of programme time were logged using the terminal during the first twelve months of servce, to which must be added many hours of vision circuit tests and standby periods.

7. Conclusions

Use of a transportable satellite earth station to extend the facilities of BBC outside broadcasting has widened the range of programme locations available to production staff where live transmissions can be originated. In the relatively short time that it has been in service using the OTS, the design of the terminal has proved to be well suited to television outside broadcast operation.

Features of the terminal that contributed to its success are the dual-redundant h.p.a. configuration, the check-receiver, frequency agility, the single-phase mains capability, and compatibility with existing radio-link vehicles.

It is intended that the terminal will operate within the ECS system when that becomes operational and transponders are available for television links. However, it may be necessary to combine the power of the two h.p.a.s to compensate for the reduced G/T of the satellite.

The BBC plans to continue using the terminal to provide circuits that would otherwise be impossible using conventional terrestrial links or where the use of such links would be prohibitively complicated.

8. References

1. HUGHES, C.D. *and* GOUGH, R.A. Results and conclusions of r.f. performance tests made by ESA. *Proceedings of the IEE International Conference on Results of Tests and Experiments with the European OTS satellite*, pp.56-64, April 1981.

2. BBC. Insertion Communication Equipment (ICE). *BBC Engineering*, **No. 98** , p.42, May 1974.

9. Appendices

9.1. Power budget

NOTES

1. Transportable earth station operating through the OTS channel 4 (spotbeam) transponder to an 8m receiving earth station.

2. Near-saturation of the satellite h.p.a. and clear weather conditions are assumed.

3. The sign of each parameter as listed, indicates the effect on the resultant C/N.

4. The G/T of the receiver in the transportable earth station is 22.1 dBK^{-1}, so the overall C/N for monitoring purposes is 13.2 dB.

Up-link

HPA power at output flange	27.0 dBW
Waveguide loss	— 1.0 dB
Antenna gain	51.0 dB
Up-link e.i.r.p.	77.0 dBW
Isotropic loss	— 207.3 dB
Atmospheric loss	— 0.5 dB
Satellite G/T (beam centre)	0.0 dBK^{-1}
Gain reduction for S.E. England	— 0.7 dB
Effective bandwidth (40 MHz)	— 76.0 dBHz
Boltzmann constant	228.6 dBWHz^{-1}K^{-1}
Effective up-link C/N	21.1 dB

Down-link

Transponder output power	11.6 dBW
Spotbeam antenna gain (beam centre)	35.5 dB
Gain reduction for S.W. England	— 3.0 dB
Down-link e.i.r.p.	44.1 dBW
Isotropic loss	— 205.5 dB
Atmospheric loss	—0.3 dB
Receiver G/T	33.5 dBK^{-1}
Bandwidth (40 MHz)	—76.0 dBHz
Boltzmann constant	228.6 dBWHz^{-1}K^{-1}
Up-link C/N contribution	— 5.0 dB
Overall C/N	19.4 dB

9.2. Test results

Measured performance using the OTS channel 4 (spotbeam) transponder and the check receiver on the terminal.

Video performance

p-p picture/r.m.s. noise ratio (25 MHz f.m. deviation).

Unweighted	41 dB
625-line weighted	50 dB
Chrominance weighted	43 dB

2T pulse/bar ratio		94 %
50 Hz bar tilt		Nil
Differential gain	black	5 %
	white	5 %
Differential phase	black	2 °
	white	2 °
Chrominance/luminance crosstalk		0.5 %
Chrominance/luminance gain inequality		0.5 dB
Chrominance/luminance delay inequality		10 ns

Sound performance

sound-in-syncs signal/noise ratio weighted	43 dBqOps
sound subcarrier signal/noise ratio weighted	44 dBqOps
sound subcarrier frequency response	±0.5 dB 50 Hz to 18 kHz

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